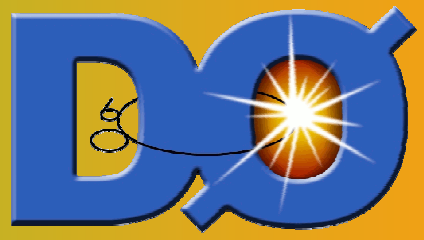


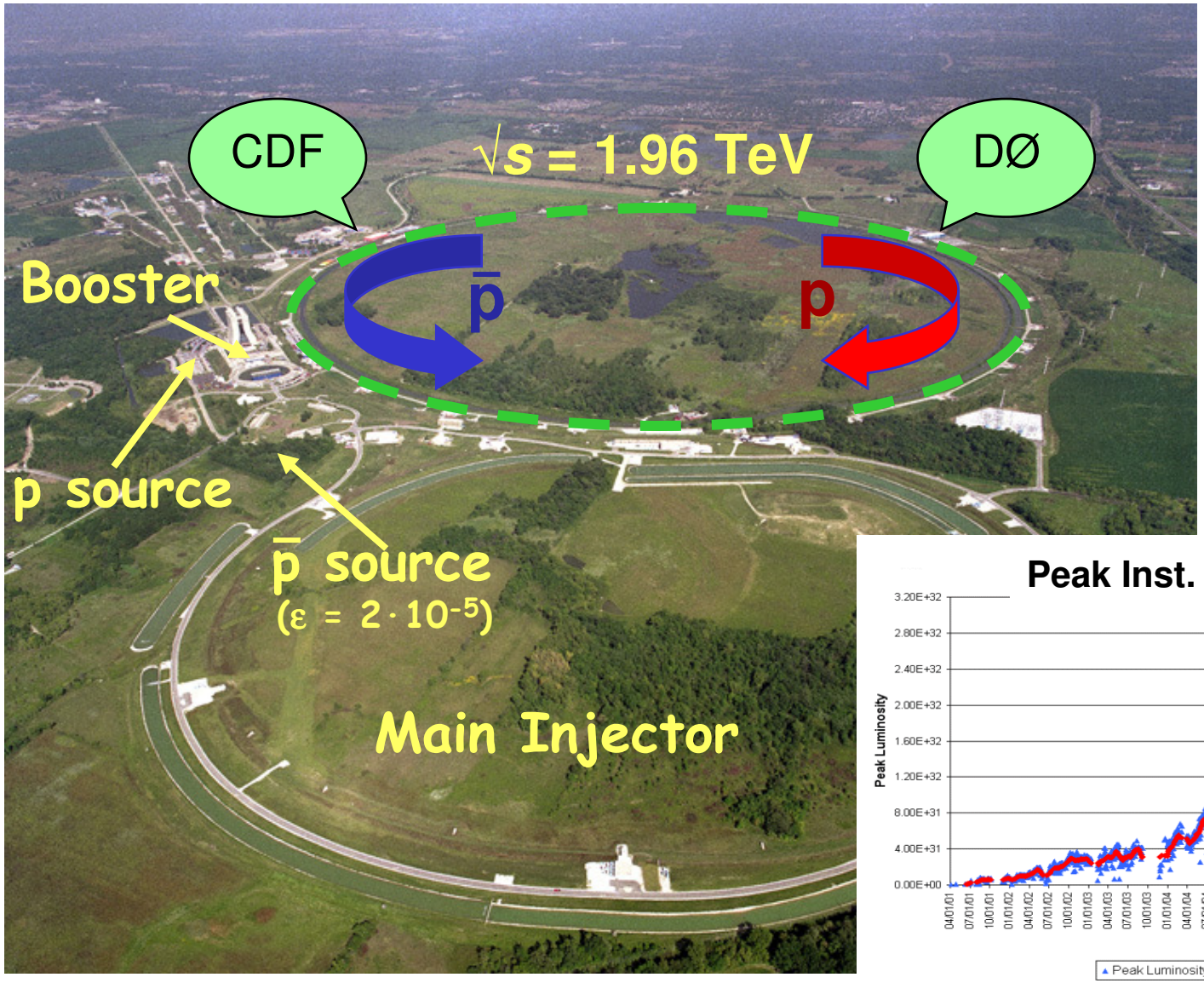
W/Z+jets and W/Z+HF Production at the Tevatron

Oriol Saltó Bauzà

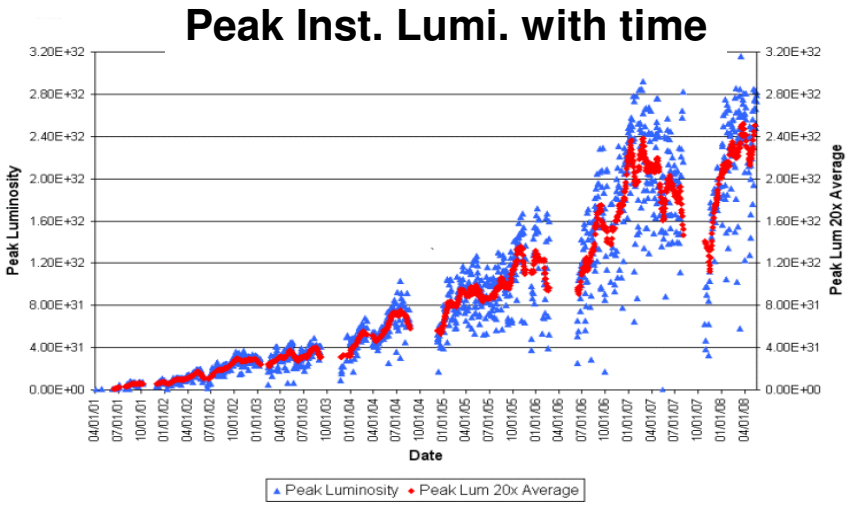
IFAE - Barcelona

for the CDF and DØ Collaborations

Tevatron

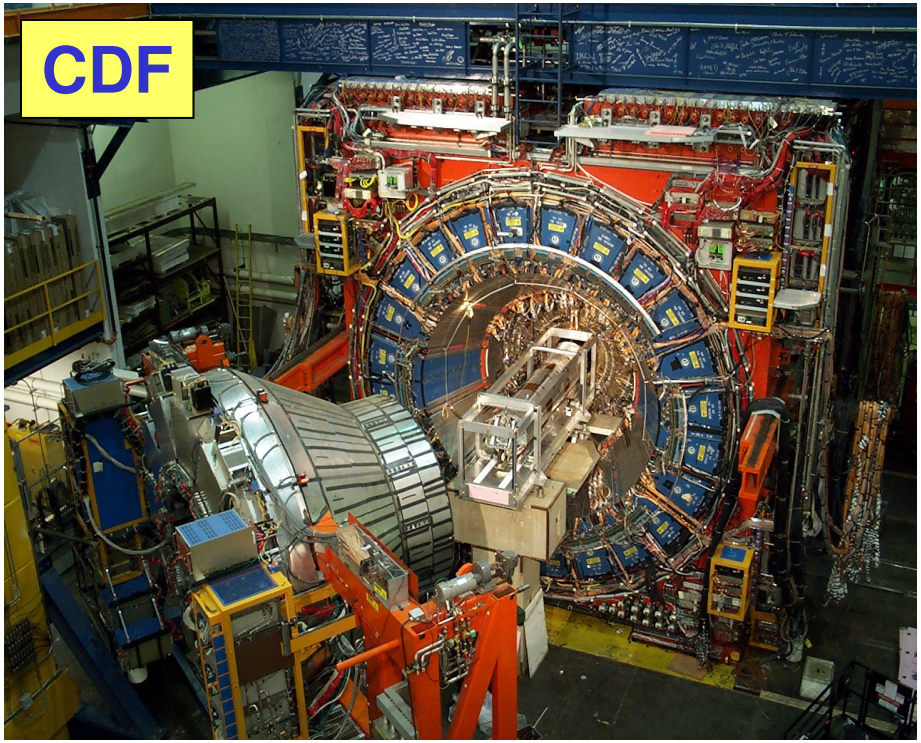


- Delivered: 4 fb^{-1}.
- Projections: between 6 and 7 fb^{-1} by 2009.
- ~3 fb^{-1} on tape.
- Analysis using up to 2 fb^{-1}.



CDF and DØ

Both experiments recording data with high **efficiency** (80-90%) and making full use of their capabilities.



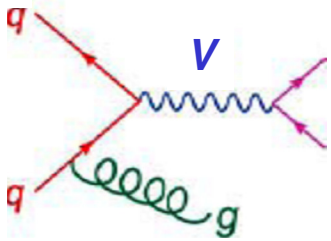
Introduction

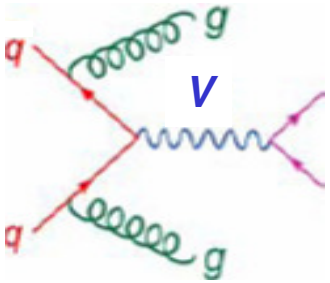
Stringent test of **pQCD** predictions.

The mass of the boson provides the necessary hard scale to perform pQCD calculations.

NLO pQCD predictions available for Boson + up to 2 jets.

Also sensitive to any new physics decays to Boson+jets.



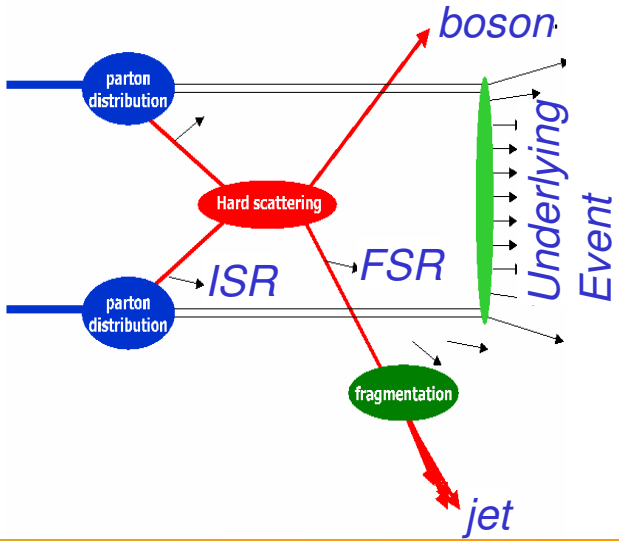


Test Ground for techniques matching Matrix Elements and Parton Shower (**ME+PS**).

Special matching algorithms (**MLM**, **CKKW**) are used to avoid double counting on ME+PS interface.

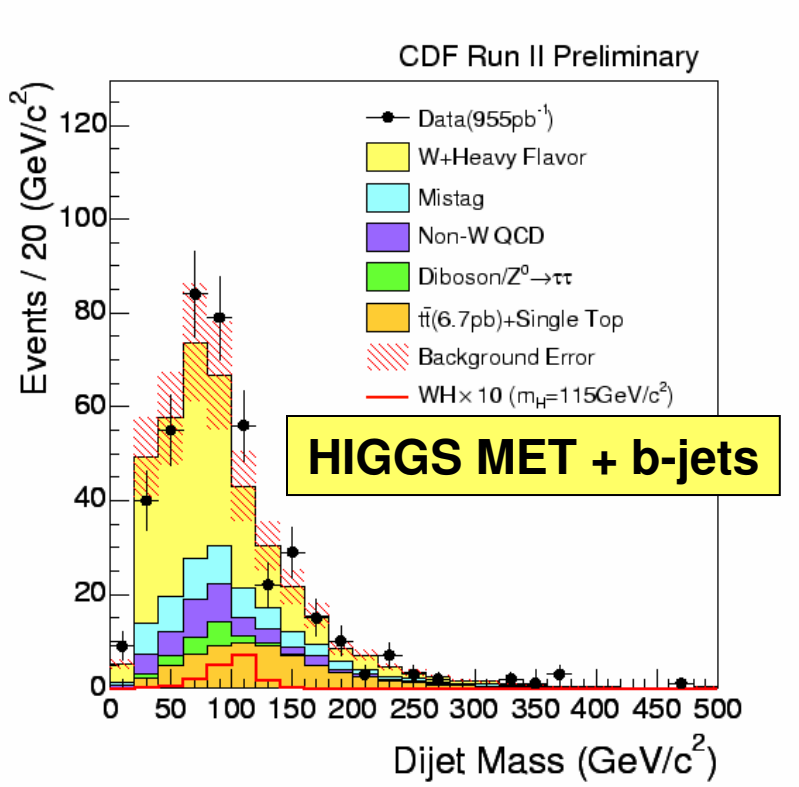
Test **non-perturbative QCD** modeling.

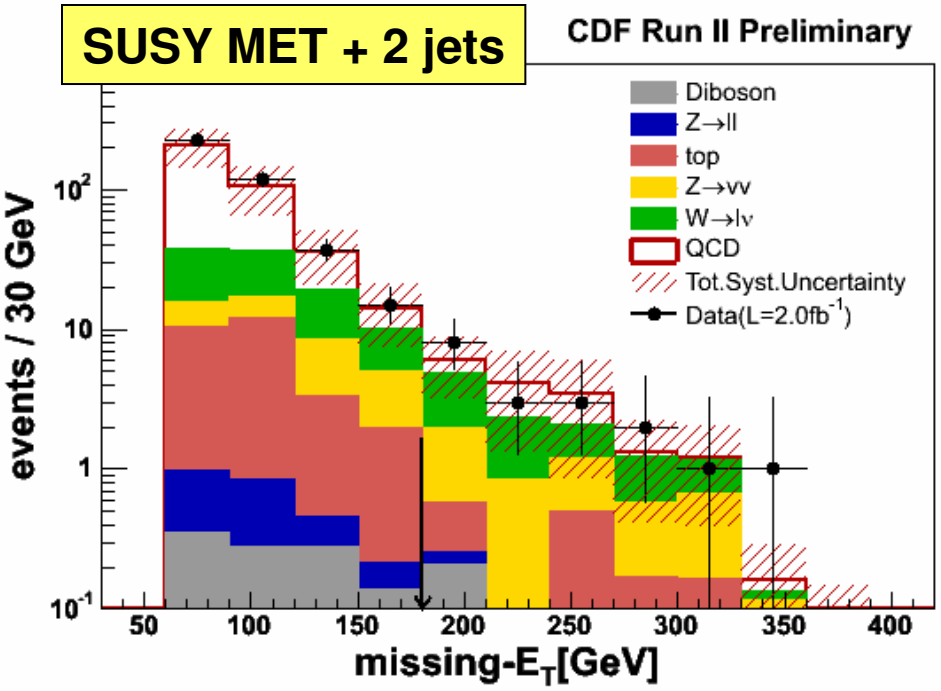
The comparison of measured cross sections (hadron level) with fixed-order pQCD predictions requires a good modeling of the **Underlying Event** (interaction between the proton remnants) and the **fragmentation** of the partons into hadrons.

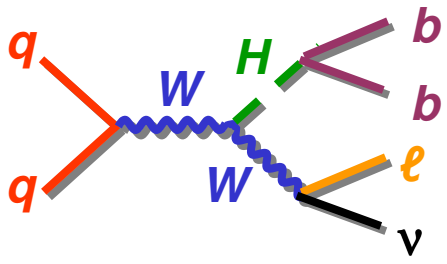


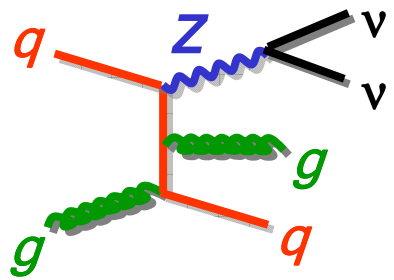
Introduction

Boson+jets constitute irreducible backgrounds for interesting SM processes (**top** production) and searches for new physics (**SUSY** and **Higgs** searches)









Outline

- **Boson + Inclusive Jet** Cross Section
  - ***W*(→*e*ν) + jets**
    - Comparison to NLO pQCD and ME+PS
  - ***Z*/γ*(→e^+e^-) + jets**
    - Comparison to NLO pQCD
    - Comparison to ME+PS
- **Boson + Heavy Flavor** Jets
  - Secondary Vertex Tagging
    - ***Z* + *b*** Jets
    - ***W* + *b*** Jets
  - Soft Lepton Tagging
    - ***W* + Single *c*** Jet
- **Summary**

"Particles, particles, particles."

W+jets

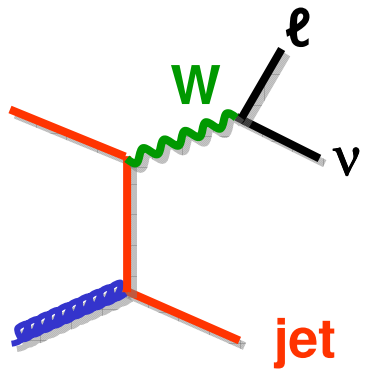
Measurement of the ***W*(→*e*ν)+jets** cross section at **hadron level** for jets with:

- $E_T > 15$ GeV and $|\eta| < 2$

and *W* decay products:

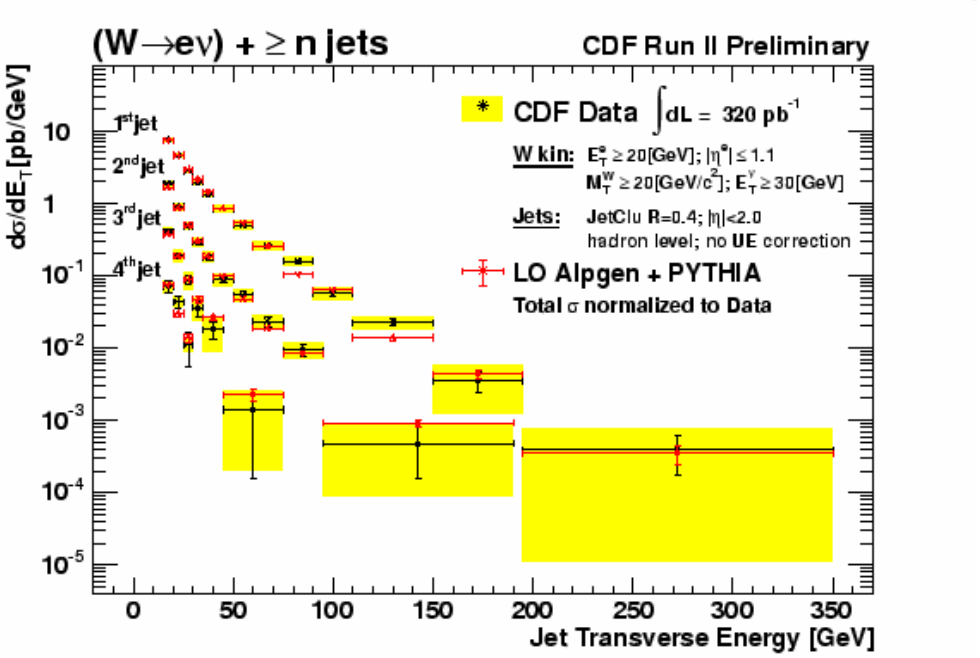
- $E_T^e > 20$ GeV, $|\eta^e| < 1.1$, $E_T^\nu > 30$ GeV and $M_T^W > 20$ GeV/c^2.

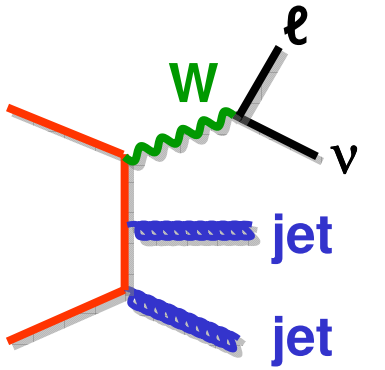
Comparisons to **NLO** pQCD and **ME+PS** predictions.



+ parton shower

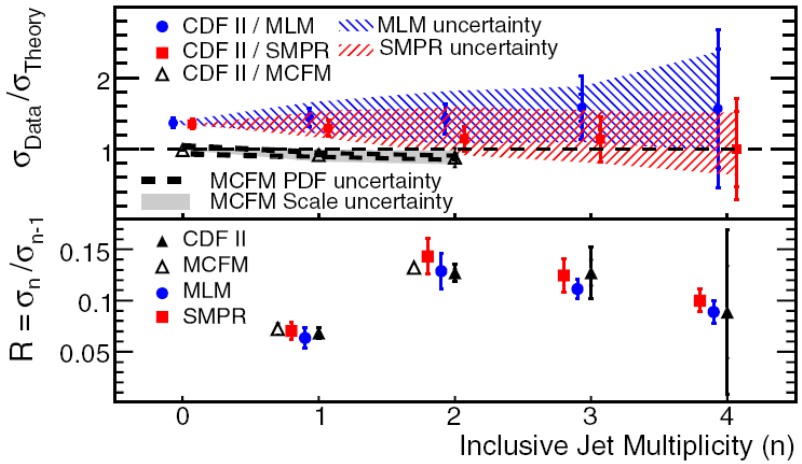
0.32 fb^{-1}



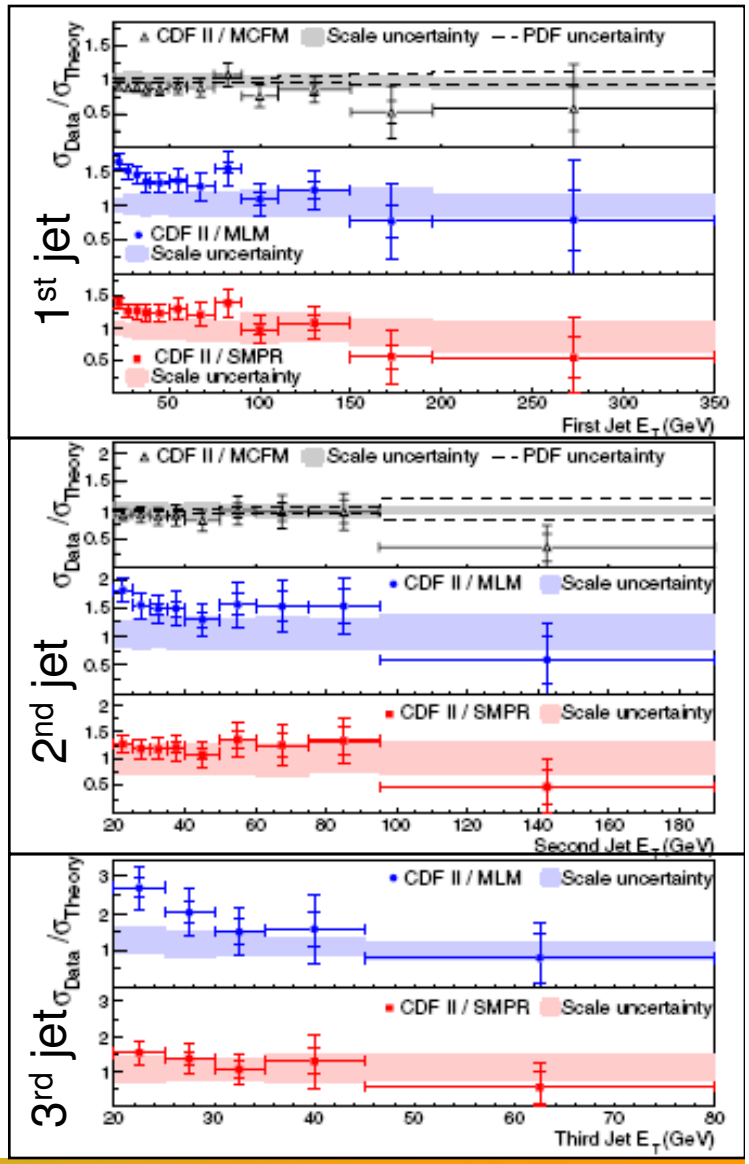


+ parton shower

W+jets



Phys. Rev. D 77, 011108(R) (2008)



Comparisons to:

- **NLO** pQCD by MCFM corrected for non-perturbative contributions
- **ME+PS**:
  - Alpgen+Herwig with **MLM** matching
  - Madgraph+Pythia with **CKKW** matching by SMPR

Predictions are a convolution of several effects (order of pQCD calculation, modeling of the UE, etc.) but in general:

- **Good agreement** with NLO pQCD predictions
- Underestimation of the LO ME+PS

Z/γ^*+jets

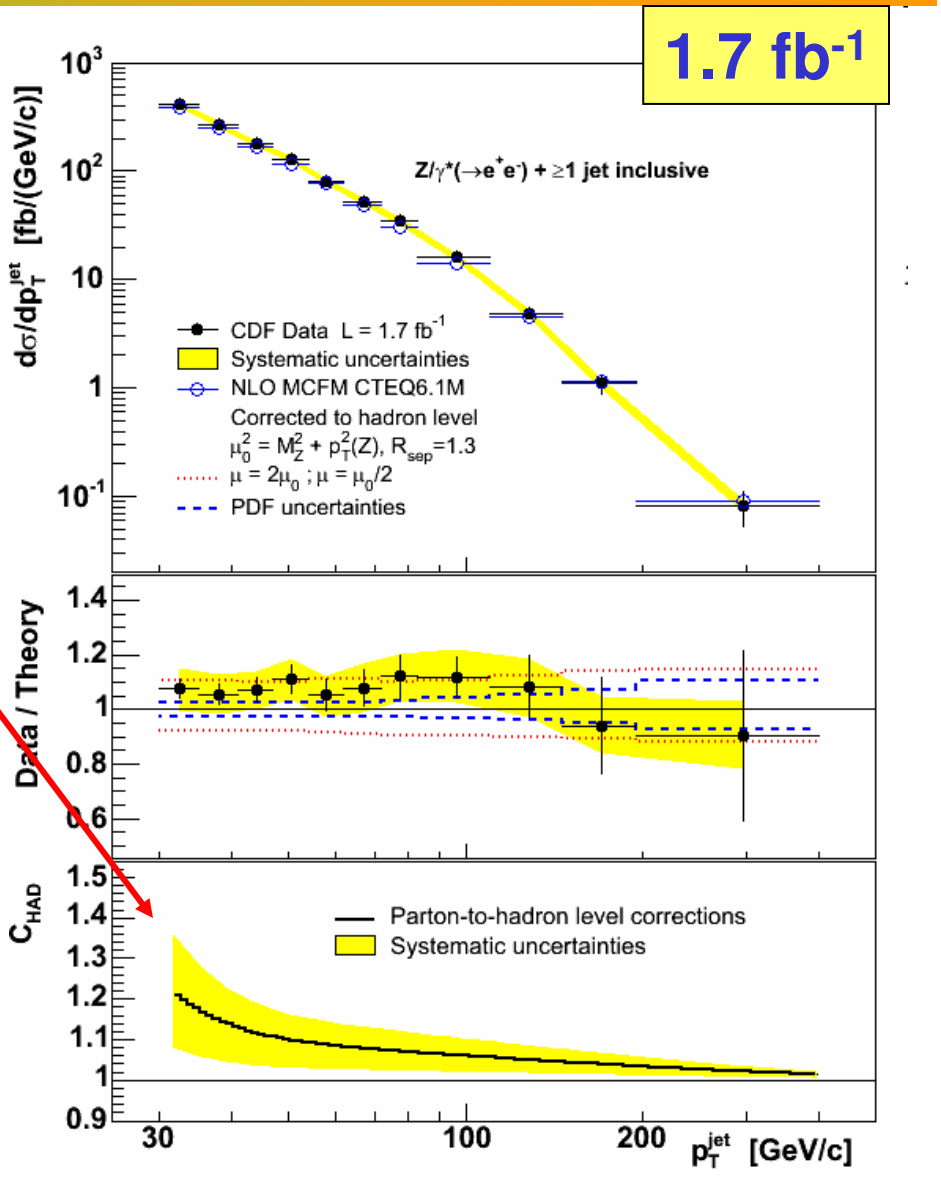
Inclusive jet cross sections in $Z/\gamma^*(\rightarrow e^+e^-)$ production.

- Measured the inclusive hadron level jet cross section in a restricted kinematic region.
- Compared to **NLO pQCD** predictions .
- Fixed-order pQCD prediction have been corrected for non-perturbative contributions (**UE** and **fragmentation**).

Kinematic region:

- $E_T^e > 25$ GeV, $|\eta^{e1}| < 1.0$, $|\eta^{e2}| < 1.0$ OR $1.2 < |\eta^{e1}| < 2.8$
- $66 < M_{ee} < 116$ GeV/c^2
- $p_T^{jet} > 30$ GeV/c, $|y^{jet}| < 2.1$

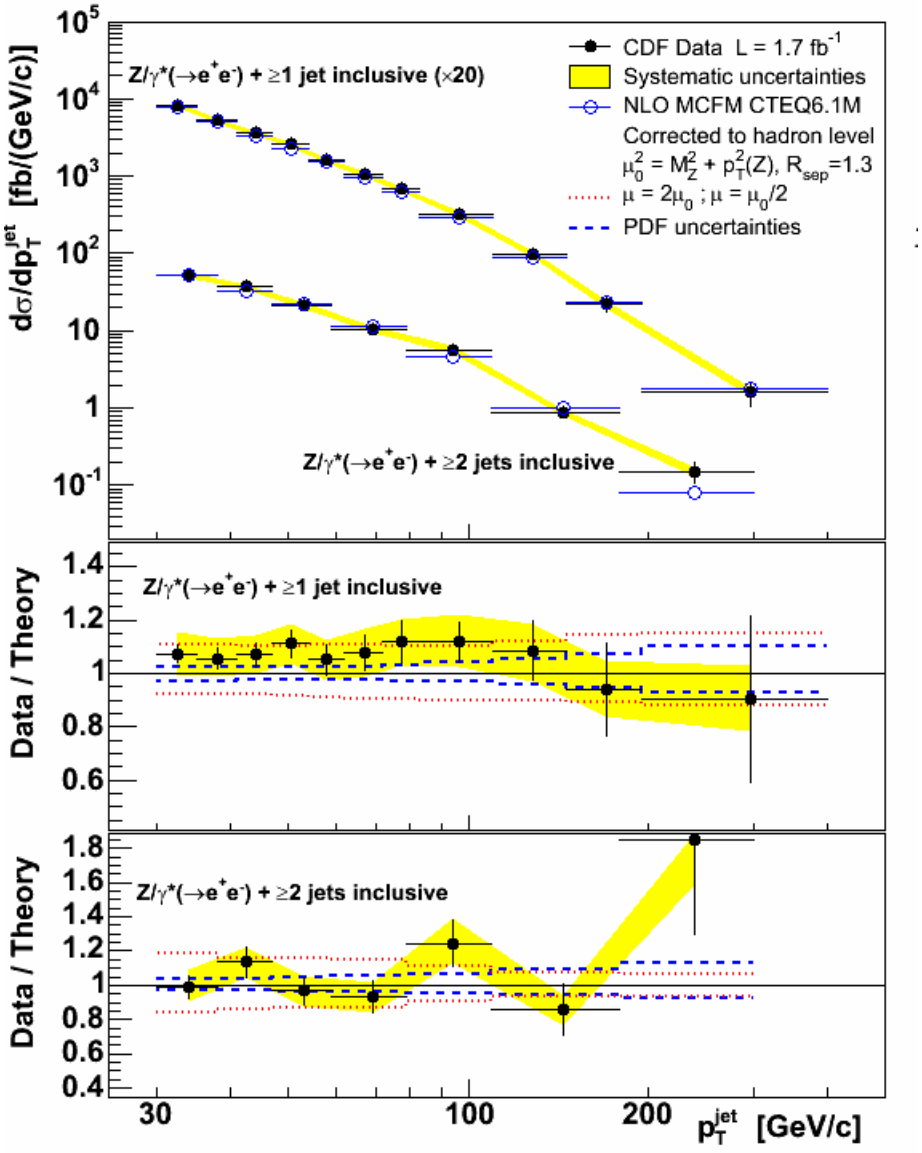
Very good agreement Data-NLO



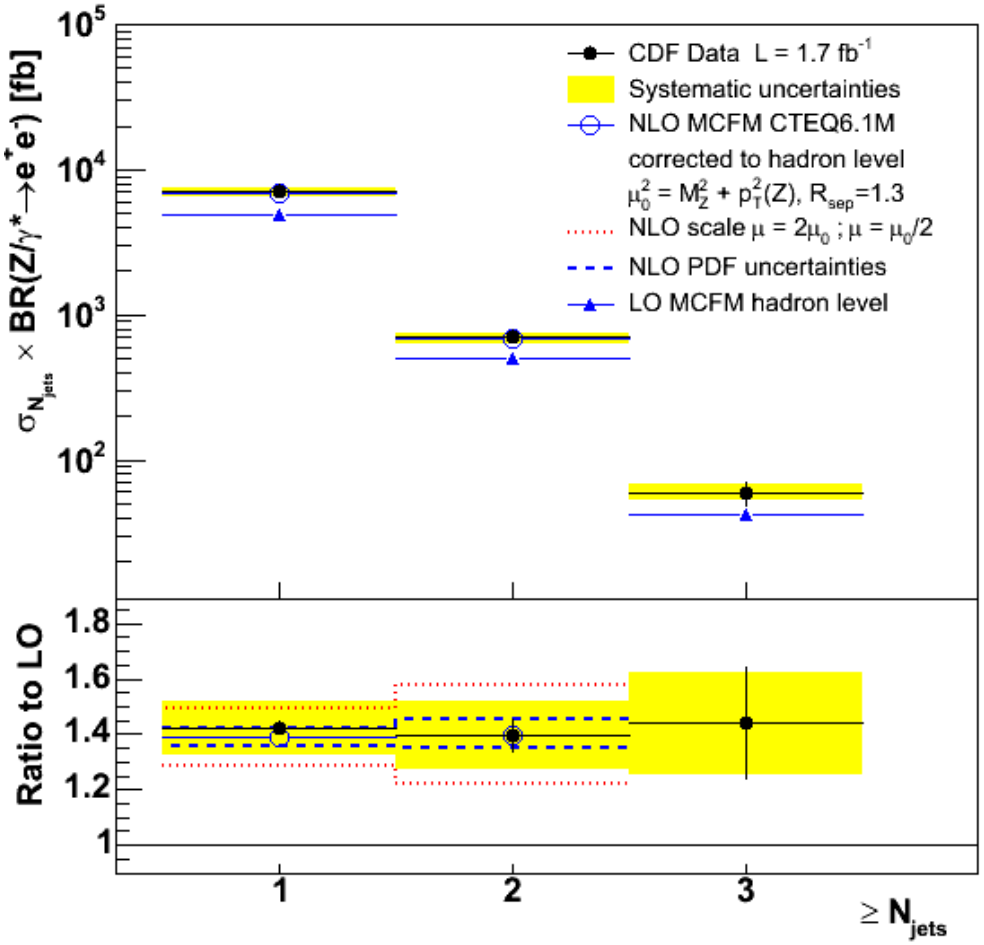
Z/γ^*+jets

NLO pQCD describe the data **accurately** in all p_T^{jet} range.

- NLO predictions available up to 2 jets in the final state
- Uncertainties in data and NLO are comparable at low p_T^{jet} (~10%).
- Uncertainties in the theoretical prediction are dominates by the dependence on the **scale**: 10% (15%) in Z/γ^* + ≥1 jet (≥2 jets).



Z/γ*+jets



LO pQCD underestimates the cross section by a factor 1.4

Data suggest a constant **NLO/LO** *k*-factor for up to 3 jets in the final state.

Both, LO and NLO, predictions include a ~15% contribution from **non-pQCD effects**.

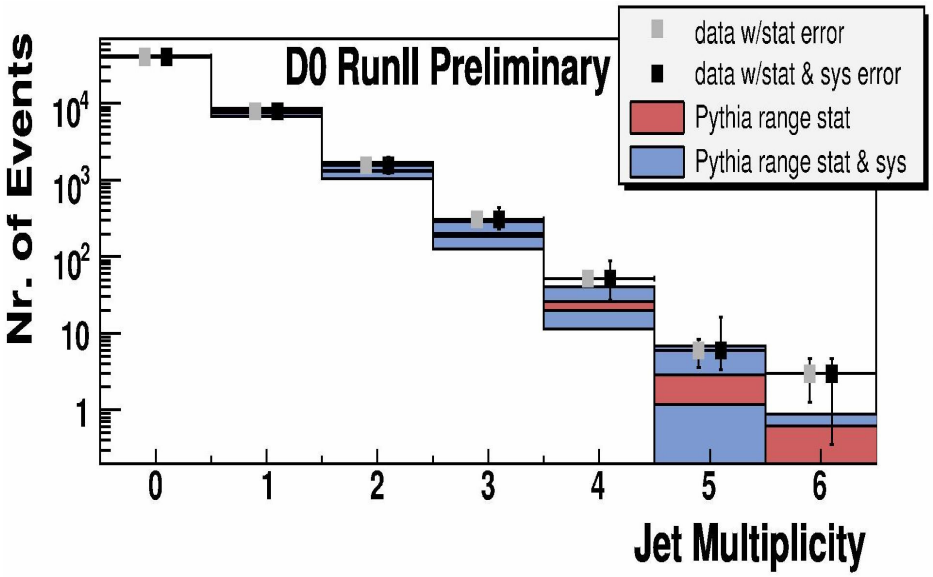
Very good agreement Data-NLO pQCD.

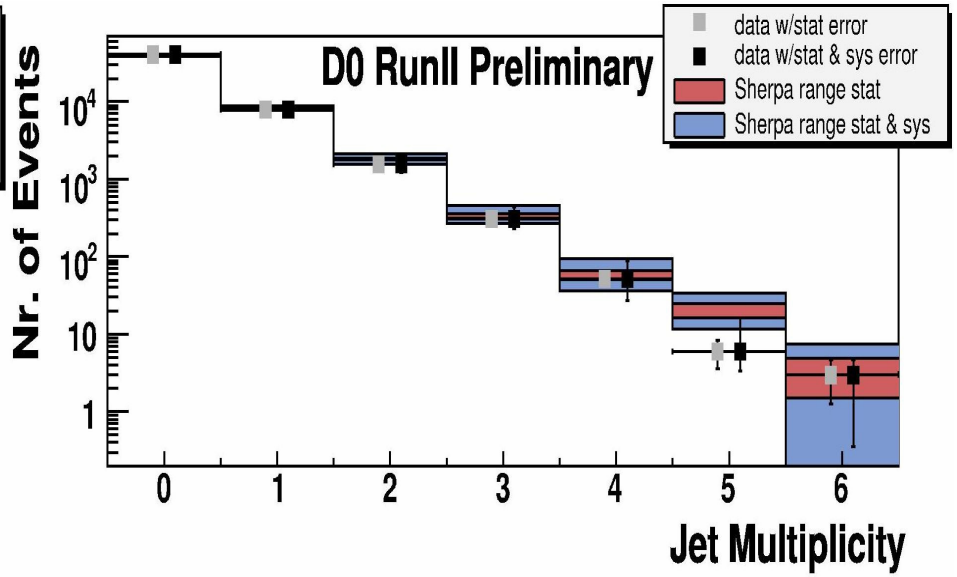
χ^2 probability of 83% (99%) for $N_{jets} \geq 1$ ($N_{jets} \geq 2$).

Z/γ^*+jets in different MC

0.95 fb^{-1}

Comparing the prediction of ***Z*+jets** done by **different MCs**:
(p_T^{jet} > 15 GeV/c)





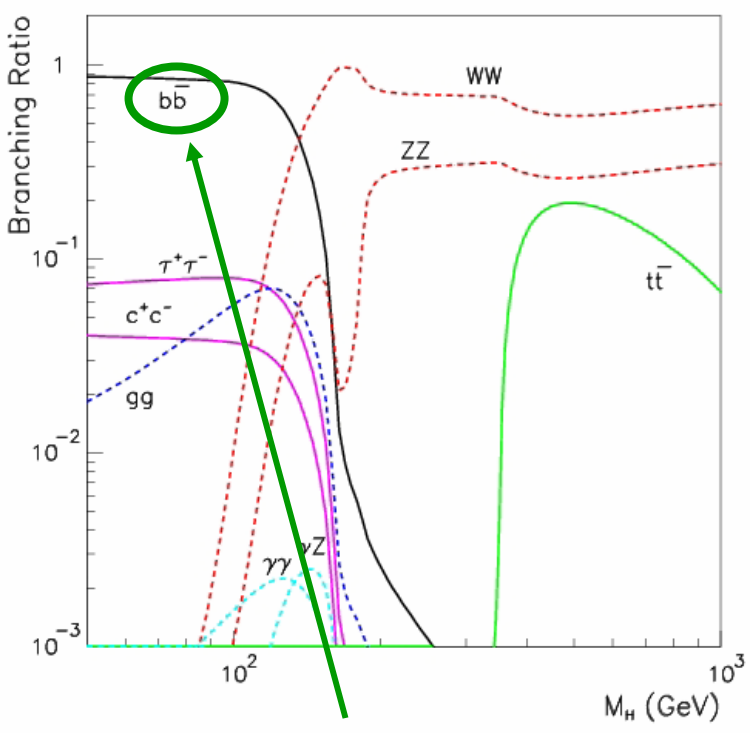
Pythia Z inclusive
Jets are created from the PS
It describes up to the 2nd jet

Sherpa Z+0…3p
ME+PS matched for every parton/jet mutiplicity
Describes better higher jet multiplicities.

Boson + Heavy Flavor Jets

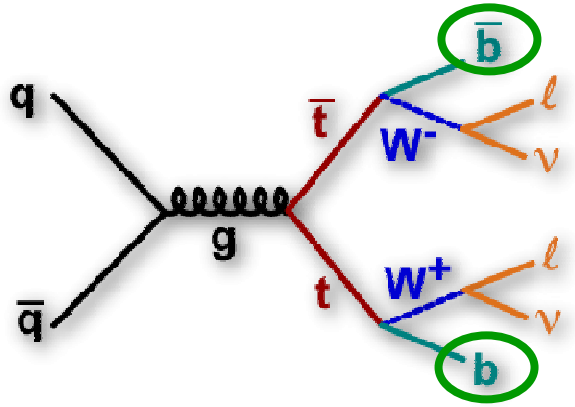
There is special interest in **Boson+HF jets** processes.

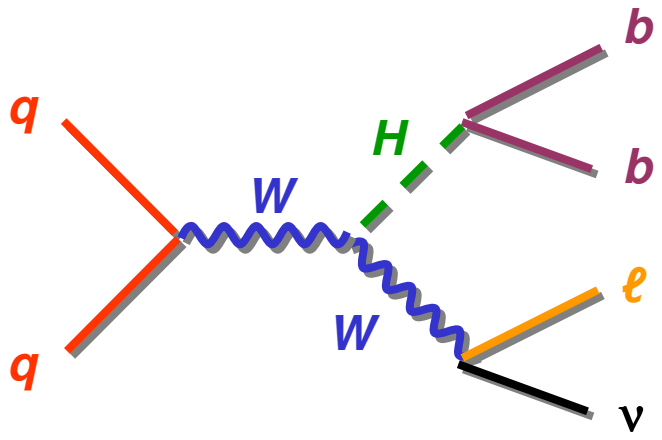
They are background to some of the most interesting processes.



Light Higgs prefers to decay in bb

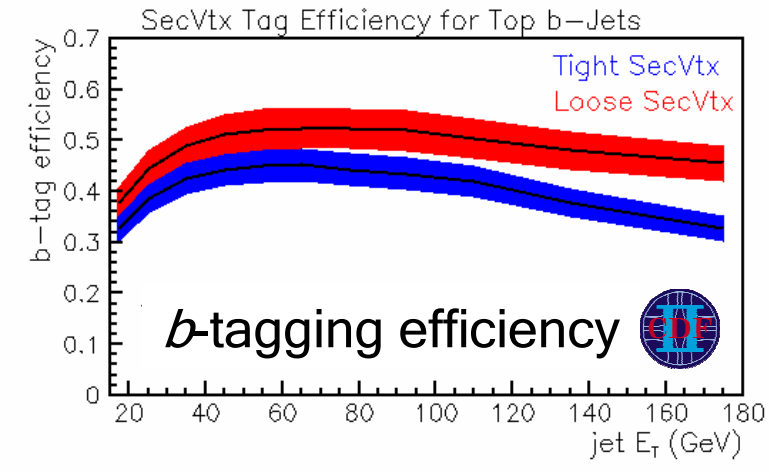
Background to top production

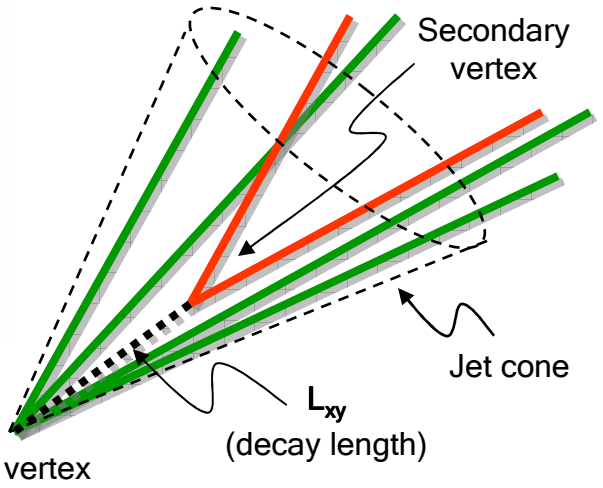




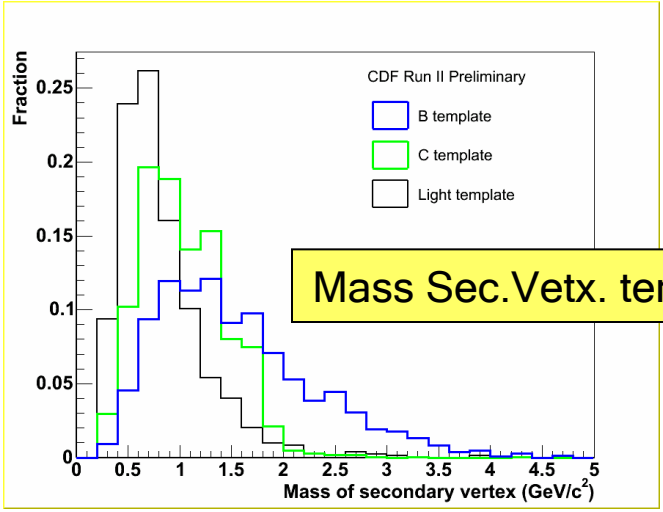
Heavy Flavor Jets (SecVtx)

Secondary Vertex algorithm (**SecVtx**) reconstructs secondary vertices inside jets. Cutting on the distance between the primary and secondary vertices rejects most of light flavor jets.

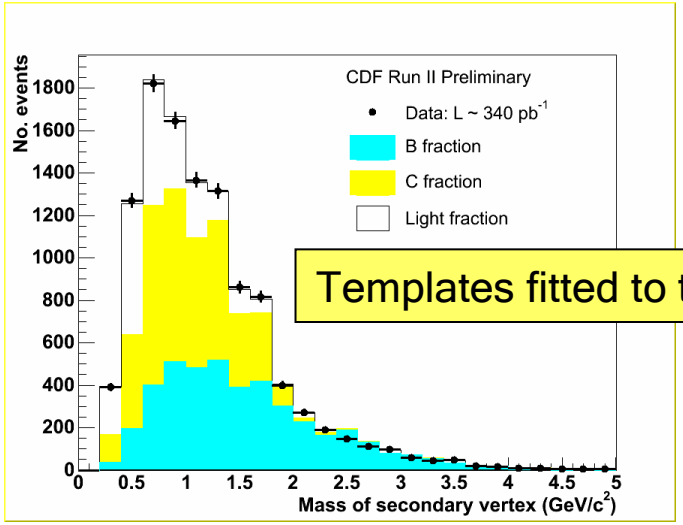




The **mass of the secondary vertex** is a powerful discriminant to extract the *b*-jet content. Templates from MC are fitted to the data.



Mass Sec.Vetx. templates



Templates fitted to the data

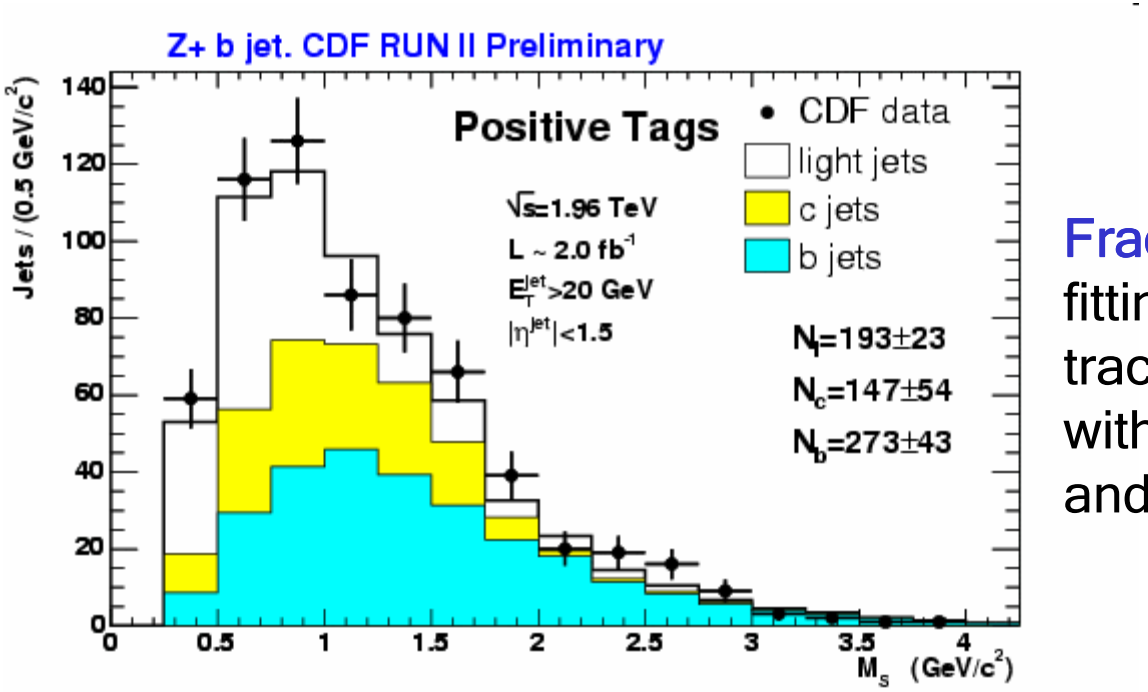
Z+b Jets

The measurement counts jets with a **secondary vertex**,

p_T > 20 GeV/c and |η| < 1.5 in $Z/\gamma^* \rightarrow \mu\mu$ and $Z/\gamma^* \rightarrow ee$ events.

The measurement is unfolded to the hadron level.

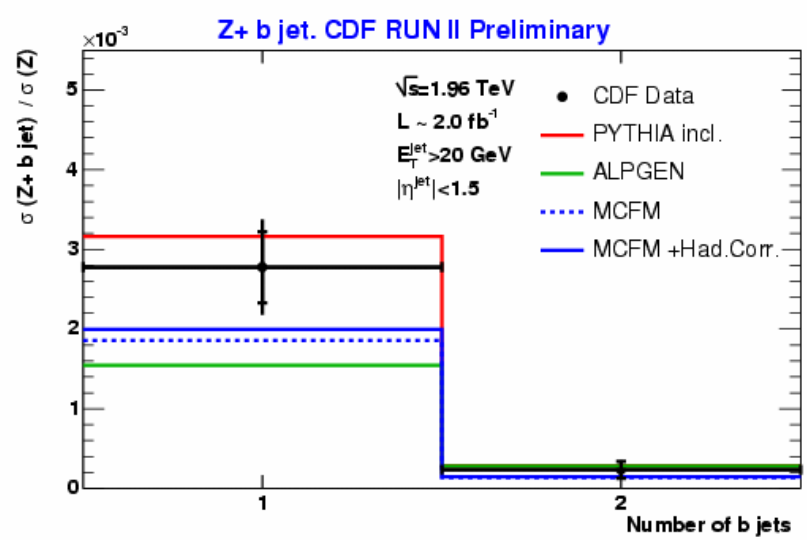
Updates the previous results with 6 times more data and includes differential distributions.

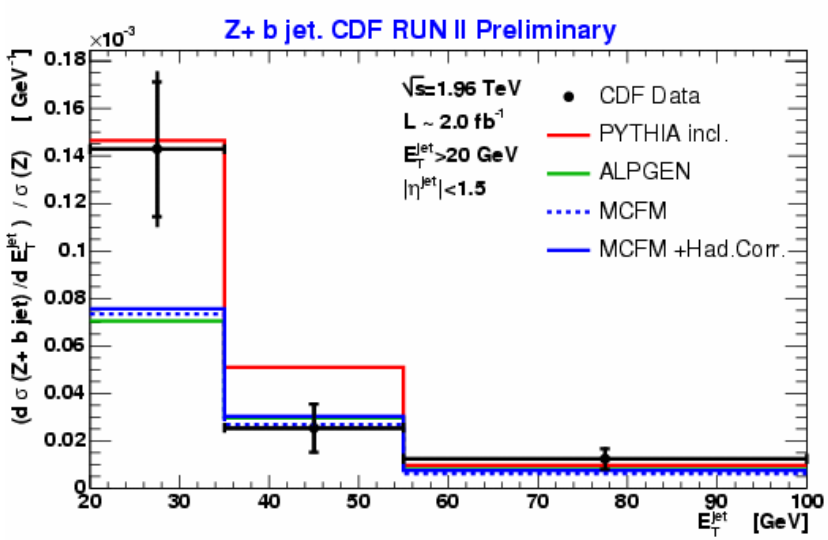


2.0 fb^{-1}

Fraction of *b*-jets obtained by fitting the invariant mass of the tracks of the secondary vertex with the templates of the light, *c* and *b* jet contributions.

Z+b Jets





	CDF Data	PYTHIA	ALPGEN	HERWIG	NLO	NLO +U.E+hadr.
$\sigma(Z+b\,\text{jet})$	$0.86 \pm 0.14 \pm 0.12$ pb	–	–	–	0.51 pb	0.53 pb
$\sigma(Z+b\,\text{jet})/\sigma(Z)$	$0.336 \pm 0.053 \pm 0.041\%$	0.35%	0.21%	0.21%	0.21%	0.23%
$\sigma(Z+b\,\text{jet})/\sigma(Z+\text{jet})$	$2.11 \pm 0.33 \pm 0.34\%$	2.18%	1.45%	1.24%	1.88%	1.77%

Data are well described by Pythia but is slightly underestimated by the NLO prediction.

Underlying Event and **hadronization** contributions obtained from Pythia (+10% and -1%)

W+b Jets

Provides a data-driven measurement of background to **single top** and **Higgs** searches.

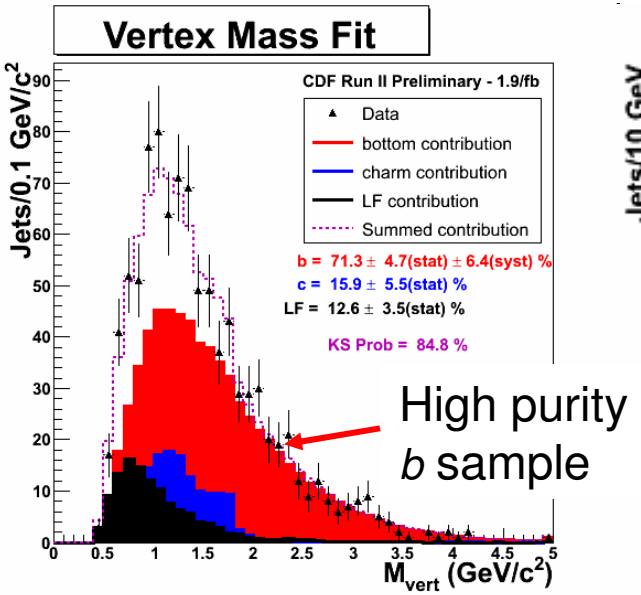
1.9 fb^{-1}

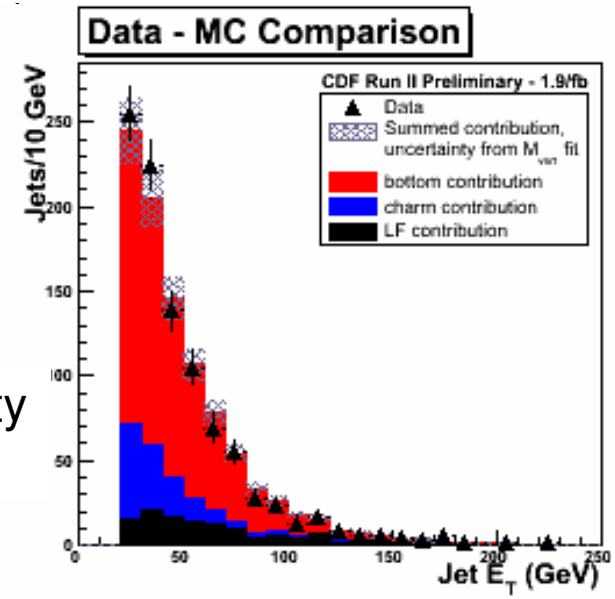
$$\sigma_{b\ \mathrm{jets}}(W + b\ \mathrm{jets}) \times BR(W \rightarrow \ell\nu) = 2.74 \pm 0.27(stat) \pm 0.42(syst)\ pb$$

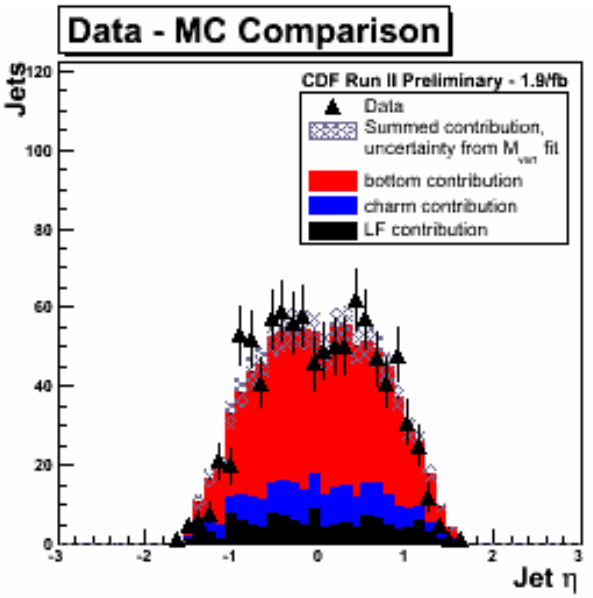
in events with a p_T > 20 GeV/c, |η| < 1.1 electron or muon, a p_T > 25 GeV/c neutrino, and 1 or 2 E_T > 20 GeV, |η| < 2.0 jets regardless of species.

ALPGEN prediction: $\sigma \times BR = 0.78\ pb$

Clear underestimation by LO prediction.



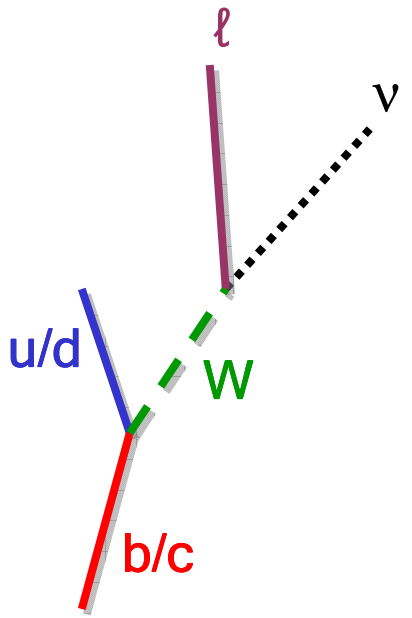


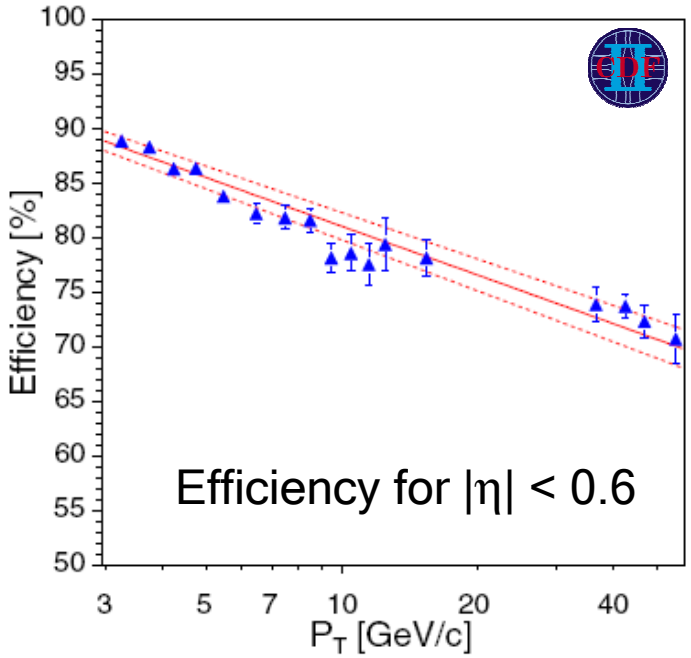


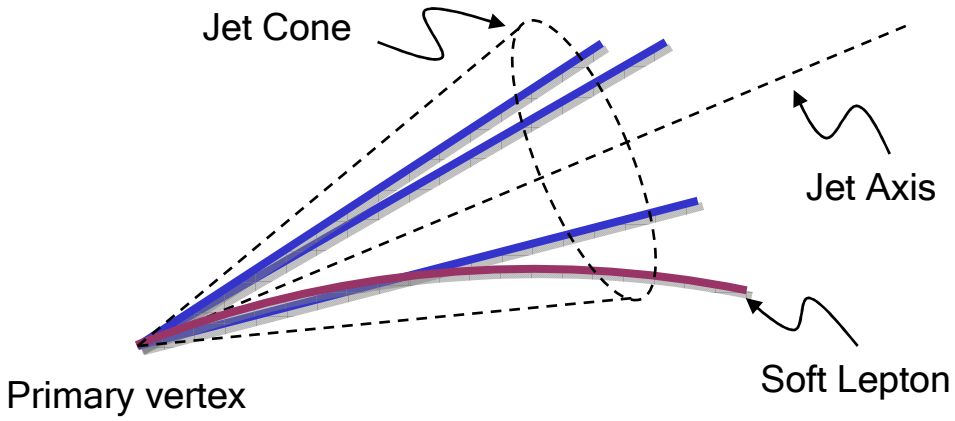
Heavy Flavor Jets (SLT)

Heavy Flavor jets can be identified by the presence of a low p_T lepton (**soft lepton** (electron or muon)) inside the jet coming from the semi-leptonic decay of a heavy quark.

In the μ case, a jet is tagged if the μ p_T>3GeV/c and it goes in the direction of the jet, and passes some track quality cuts.







W + Single c Jet

First direct measurements of this cross section.

Probes the **gluon** and ***s*-quark** PDF in the proton.

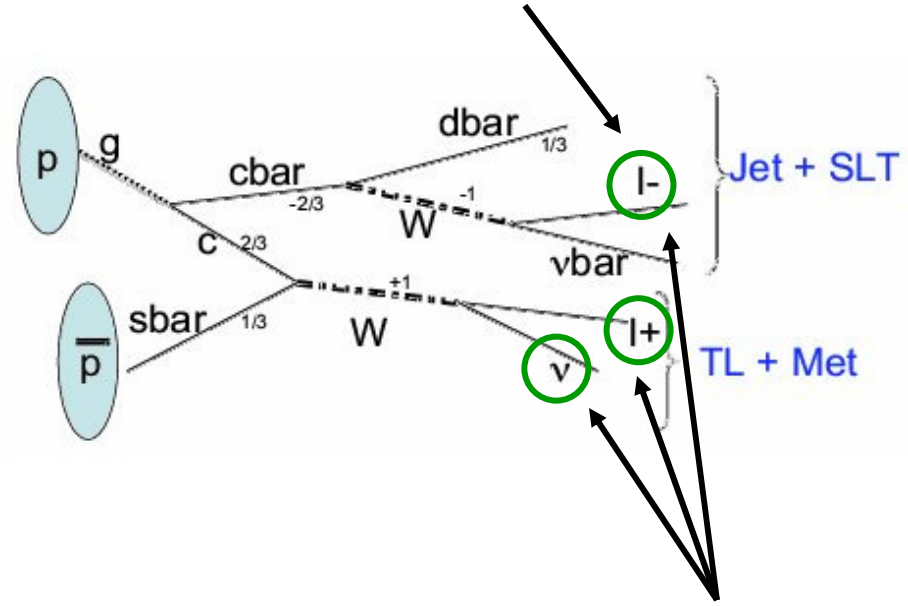
***c*-jets** identified by the presence of a **soft muon** inside the jet from the semi-leptonic decay of the *c* quark (**SLT$_\mu$ jet**)

For ***W+c***, the soft muon in the SLT jet and the lepton from the W must have **opposite sign**.

Observable: N^{OS}-N^{SS}

- Used to distinguish the signal from W+cc and W+bb, where N^{OS}-$N^{SS} \approx 0$
- Definition of **Asymmetry**:

$$A = \frac{N^{OS} - N^{SS}}{N^{OS} + N^{SS}}$$



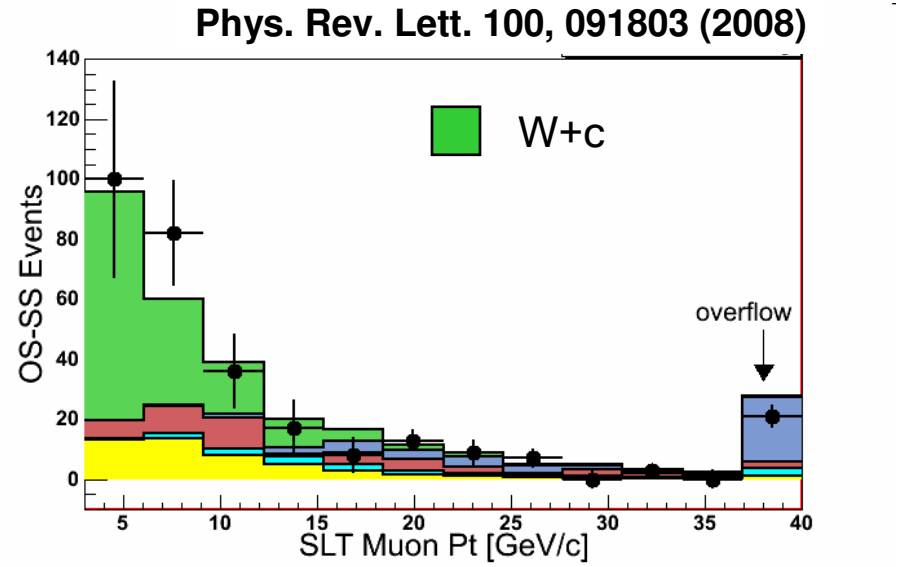
Events selected by the presence of a **SLT jet**, in addition to a charged **lepton** and **MET** from the W decay.

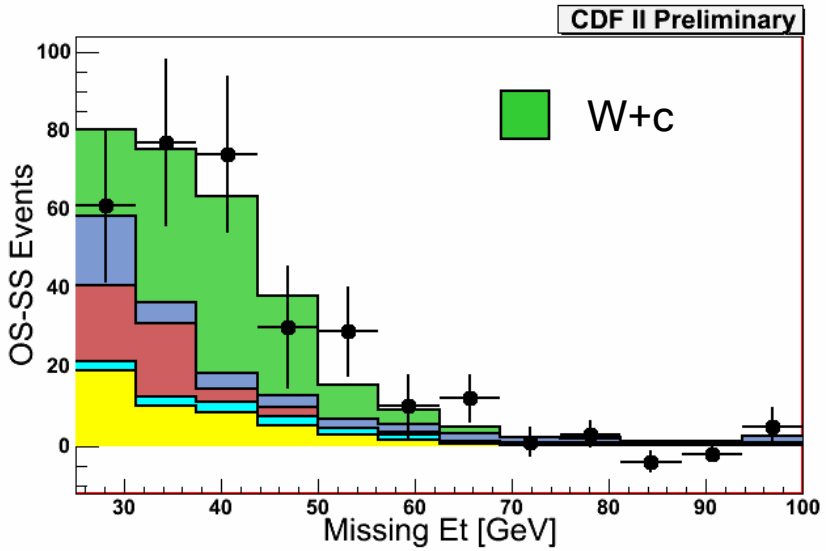
W + Single c Jet

1.8 fb^{-1}

$$(N^{OS} - N^{SS})_{measured} = 298$$

W+c contribution scaled to the number of (OS-SS) observed





Cross section for $p_T(c) > 20$ GeV/c and $|\eta(c)| < 1.5$

$$\sigma_{Wc} = \frac{N_{tot}^{OS-SS} - N_{bkg}^{OS-SS}}{A \cdot Acc \cdot \int L}$$

Asymmetry

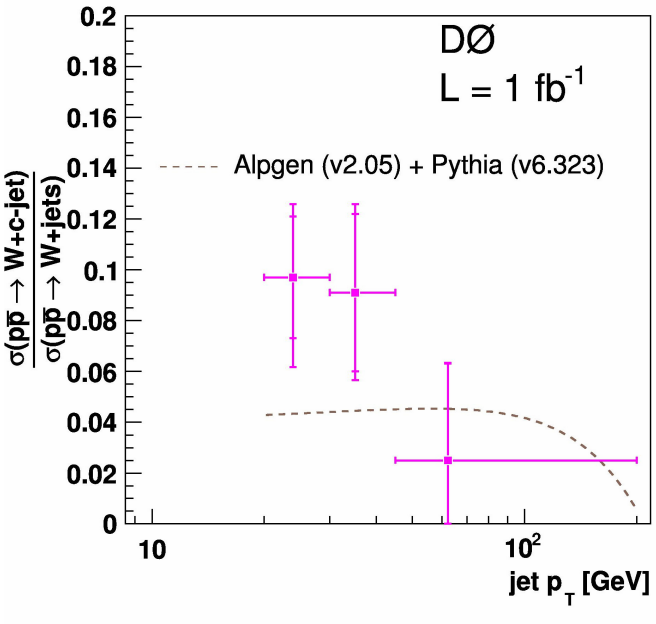
$$\sigma_{Wc} \times BR(W \to \ell\nu) = 9.8 \pm 2.8(stat)\,^{+1.4}_{-1.6}(syst) \pm 0.6(lum)\,pb$$

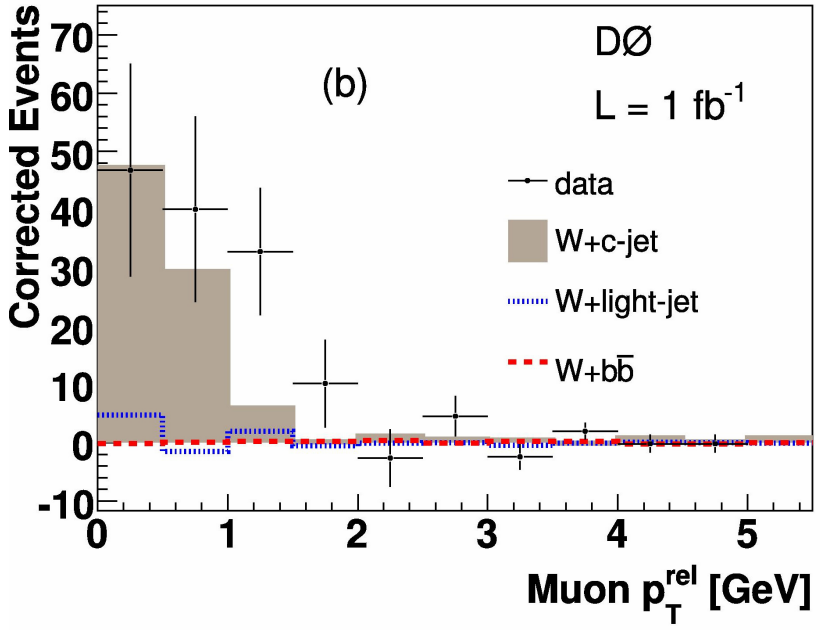
in agreement with the NLO pQCD prediction: $11.0\,^{+1.4}_{-3.0}\,pb$

W + Single c Jet

Also using the **charge correlation** in $W(\rightarrow \ell\nu)+c$ events

1.0 fb^{-1}





$$\frac{\sigma(W+c\text{-}jet)}{\sigma(W+jets)} = 0.071 \pm 0.017$$

Alpgen+Pythia prediction

$$\frac{\sigma(W+c\text{-}jet)}{\sigma(W+jets)} = 0.040 \pm 0.003(PDF)$$

Measurement dominated by statistical uncertainties.
Reasonable agreement with Alpgen+Pythia prediction.

Summary

- Boson + jets measurement play a critical role in the Tevatron Run II physics program.
- Predictions on **Boson + inclusive jets** have been intensively studied.
  - NLO pQCD predictions describe accurately the measurements on data.
- Description of **Boson + HF jets** is an open business.
  - The new results suggest discrepancies between data and NLO pQCD calculations.
  - Further studies promise to bring some light to the subject
- The understanding of Boson + jets final states will be crucial at the LHC.